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Heterosis Studies for Yield and its Components in Rice Hybrids using CMS system

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Abstract: Realizing the potential of hybrid rice to increase productivity, the present experiment was undertaken with a fixed model i.e. line x tester mating design involving 3 CMS lines and 20 elite restorers to identify the best heterotic combination. The results indicated that the manifestation of heterobeltiosis for grain yield was significantly superiority of 43 hybrids ranging from 11.63 to 113.04% and 46 hybrids over standard variety (Sarjoo-52) ranging from 10.48 to 71.56%. Most of the crosses which exhibited superiority over better parent or standard variety for grain yield also showed significant heterosis for number of fertile spikelets and number of spikelets per panicle. These crosses also possessed about 80% pollen viability. Besides grain yield, considerable heterosis was observed for other characters also but its degree varied from character to character. The best cross combination in order of merit grain yield and other yield components were IR58025A×IR48749-53-2-2-2R,NMS4A×IR633-76-1R,IR58025A×IR54853-43-1-3R,IR58025A×IR19058-107-1R and PMS10A×IR54853-43-1-3R. Considering the heterosis more than 60% as well as significant *sca* effects for major components, the NMS4A×IR633-76-1R, IR58025A×IR19058-107-1R and IR58025A×IR32419-28-3-1-3R were most promising combinations and need to be tested on large scale. Besides these, some other crosses viz., NMS4A×IR52256-9-2-2-1R, NMS4A×IET 9352 and IR58025A×IET201102, which expressed more than 50% heterosis along with desirable significant *sca* effects for more than six important yield components, may be considered for commercial exploitation.

Key words: Rice, hybrid vigour, heterobeltiosis, standard heterosis, yield, agro-morphological traits

INTRODUCTION

Rice (*Oryza sativa* L.) is the most important food crop of India with world ranking first in area and second to China in production. At the current growth of population rice requirement increases dramatically; hence, it is challenging task to ensuring food and nutritional security to the country. Therefore, enhancing productivity of rice through novel genetic approaches like hybrid rice was felt necessary. Exploitation of heterosis is considered to be one of the outstanding achievements of plant breeding. The presence of sufficient hybrid vigour is an important pre-requisite for successful production of hybrid varieties. Hybrid vigour in rice was first reported by Jones (1926). According to Malthus (1989) the food grains increase in arithmetical progressions while the population increases in geometrical progression, thus improved technologies are required to bridge the gap to feed the increasing population. Therefore, for breaking the yield barrier level and make rice cultivation more attractive, it is now necessary to explore alternative approaches. Among the all possible alternatives, heterosis is an important approach for increasing rice production. It has not only contributed to food security, but has also benefited the environment (Duvick, 1999). The various crop species in which hybrid varieties are used commercially, rice ranks very high. Heterosis has been commercially exploited in rice with a yield advantage of 20-25% over the best pure lines (Rather *et al*., 2001). Hybrids offer opportunity to break through the yield ceilings of semi dwarf rice varieties. Hybrids have already been successfully used in maize, pearl millet and sorghum. The discovery of Cytoplasmic Male Sterility (CMS) in rice (Athwal and Virmani, 1972; Erickson, 1969; Shinjyo, 1969) suggested that breeders could develop a commercially viable F_1 hybrid, but little serious interest was paid until Chinese scientists reported successful production of F_1 rice hybrids in China (IRRI, 1977). Those hybrids yielded

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20-30% higher than conventionally bred varieties (Lin and Yuan 1980; Shen 1980). Significant heterosis, heterobeltiosis and standard heterosis have been reported in rice by a number of workers (Nijaguna and Mahadevappa, 1983; Panwar *et al*., 1983; Yoshida and Fujimaki, 1984; Devarathinam, 1984; Cheema and Awan, 1985; Peng and Virmani, 1991; Vivekanandan, 1991; Lokaprakash *et al*., 1992; Wilfred and Prasad, 1992; Watanesk, 1993; Patel *et al*., 1994; Zhang *et al*., 1994; Ali and Khan 1995; Rao *et al*., 1996; Mishra and Pandey, 1998; Nuruzzaman *et al*., 2002; Li *et al*., 2002; Faiz *et al*., 2006; Saleem *et al*., 2008; Rashid *et al*., 2007; Bagheri and Jelodar, 2010; Rahimi *et al.,* 2010). The increased yield of rice hybrids alone does not ensure profitability to farmers if their grain quality is not acceptable and if they fetch a low price in the market. Khush *et al.* (1988) studied this subject intensively and concluded that hybridity *per se* did not harm grain quality in terms of physical and chemical characteristics as long as both parents possess acceptable grain quality, hybrid rice breeding programs must give emphasis (if they have not done so in the past) to the critical evaluation of parental lines and hybrids for grain quality before these are released for commercialization. Most of the Asian countries have been able to keep pace between rice production growth rate and that of population during the last four decades. After a brief review of rice research in India and considering the gains obtained through green revolution technologies, the possibilities and prospects of utilizing the gene revolution technologies are considered for further enhancing the production and productivity of rice for not only ensuring food security but also nutritional security. Rigorous efforts are needed to improve the production of rice in the country by diversifying its uses and by developing rice hybrids for specific traits of economic importance. Identifying high yielding hybrids is expensive and involves testing large number of hybrid combinations in multi environmental trials therefore; the present investigation was aimed to evaluate rice hybrids for yield, adaptability and grain quality for successful commercial utilization.

MATERIALS AND METHODS

The parental material comprised 3 CMS lines viz; IR58025A, NMS4A and PMS10A used as females (lines) were crossed with 20 diverse genotypes used as male (testers) in a line x tester mating design in 2001-02. Thus, the resultant sixty hybrids along with their 23 parents and one standard check variety (Sarjoo-52) were evaluated in a randomized block design with three replications at Crop Research Station-Masodha, Narendra Deva University of Agriculture and Technology, Kumarganj, Faizabad during 2002-03. Each genotype was raised in 2.5 m long single row plot keeping 20×15 cm spacing. The recommended agronomic practices followed to raise good crop stand. The data were recorded on 10 randomly selected plants from each replication for various quantitative traits studied were viz., days to 50% flowering, plant height (cm), pollen fertility (%), effective tillers per plant, panicle length (cm), number of spikelets per panicle, number of fertile spikelets, spikelet fertility (%), 100 grain weight (g), grain yield per plant (g), biological yield (g) and harvest index (%). The general reference for data collection was standard evaluation system for rice (Anonymous, 2002; Virmani *et al*., 1997). The percent increase or decrease of F_1 hybrids over better parent as well as standard check was calculated to estimate possible heterotic effects for above mentioned parameters (Fonseca and Patterson, 1968):

$$\text{Hbt\%} = \frac{\text{F1} - \text{BP}}{\text{BP}} \times 100$$

$$\text{Hs\%} = \frac{\text{F1} - \text{SV}}{\text{SV}} \times 100$$

where, Hbt = Heterobeltiosis, Hs = Standard Heterosis. To estimate significant differences among hybrids and parents, the mean data of each character were subjected to Analysis of Variance (ANOVA) as suggested by Steel and Torrie (1980). The characters showing significant differences were subjected to heterosis calculation. Deviation of F_1 from its either of the parental values was interpreted by Mather and Jink (1977) depicting type of gene action operating for controlling the trait. The t' test was applied to determine significant difference of F_1 hybrid means from respective mid parent and better parent values using formulae as reported by Wynne *et al.* (1970).

RESULTS AND DISCUSSION

The analysis of variance (Table 1) revealed that highly significant differences among lines (females) for various characters under studied i.e., days to 50% flowering, effective tillers per plant, panicle length (cm), number of spikelets per panicle, number of fertile spikelets, spikelet fertility%, grain yield per plant, biological yield, harvest index except plant height, pollen fertility and 100 grain weight while, variance among males (testers) were highly significant for all traits. The variances among crosses due to males and females (lines×testers) interaction component, indicating their *sca* effects were highly significant for all the traits except for 100 grain weight. The predominance of *sca* effects suggested that dominance and epistatic gene interactions were important for controlling these traits confirming the

Table 1: Analysis of variance for combining ability for different characters in rice

Source of variation	d.f	Days to50% flowering	Plant height (cm)	Pollen fertility (%)	Effective tillers per plant	Panicle length (cm)	No. of spikelets per penicle
Replications	2	4.148	2.664	8.663	28.509	0.896	4.771
Treatments	82	58.77**	149.523**	800.797**	19.779*	45.394**	743.789**
Female (lines)	2	6.208**	0.333	0.65	31.55**	15.393**	1695.517**
Males (testers)	19	31.542**	98.234**	12.289**	21.396**	33.957**	698.588**
Females×Males (lines×testers)	38	37.58**	88.69**	27.282**	15.831**	60.736**	853.606**
Parents	22	78.993**	98.753**	2789.196**	22..534**	31.963**	441.573**
Crosses	59	34.572**	88.768**	21.551*8	18.156**	50.575**	832.031**
Parents vs Crosses	1	1041.531**	4855.013**	3031.476**	54.916**	34.995**	2192.517**
Error	164	2.689	4.742	7.106	1.599	2.723	4.596
Source of variation	d.f	No. of fertile spikelets	Spikelet fertility (%)	100-grain weight (g)	Grain yield per plant (g)	Bilogical yield (g)	Harvest index (%)
Replications	2	31	8.173	0.263	31.286	4.427	53.447
Treatments	82	2903.65**	827.503**	1.057**	191.073**	279.939**	293.609**
Female (lines)	2	635.783**	28.246**	0.163	272.393**	248.321**	221.319**
Males (testers)	19	392.365**	27.045**	1.04**	79.233**	131.482**	105.606**
Females×Males (lines×testers)	38	488.675**	23.922**	0.519	97.672**	226.82**	112.445**
Parents	22	7502.783**	2262.308**	1.922**	238.647**	332.089**	660.198**
Crosses	59	462.647**	25.074**	0.674	97.657**	196.847**	113.934**
Parents vs Crosses	1	45742.06**	16604.69**	4.595**	4655.558**	4036.336**	2829.241*
Error	164	6.407	2.327	0.052	2.57	4.927	5.173

* Significant at 5% level and **1% probability level of significance

earlier findings of Janardhanam *et al.* (2000), Satyanarayana *et al.* (2000), Panwar (2005), Saravanan *et al.* (2006), Kumar *et al.* (2006) and Salgotra *et al.* (2009).

Estimation of heterosis: Heterosis was computed as percent increase or decrease in F_1 value over better parent (heterobeltiosis) and over best commercial variety (standard heterosis) were presented in Table 2. The relative magnitude of heterosis over better parent and standard variety, (Sarjoo-52) were studied for 12 characters viz., days to 50% flowering, plant height, pollen fertility, panicle bearing tillers (i.e., effective tillers) per plant, panicle length, number of spikelets per panicle, number of fertile spikelets, spikelet fertility percent, 100 grain weight, grain yield per plant, biological yield per plant and harvest index in 60 crosses. The nature and magnitude of hybrid vigour differed for different traits in various hybrid combinations. The five best cross combination and *per se* performance were given in Table 3. The salient results obtained on different aspects and conclusions drawn from the experiment are summarized below.

Days to 50% flowering: Negative heterosis is desirable for days to flowering because this will make the hybrids to mature earlier as compared to parents. Almost all the crosses had either equal or early flowering than the standard variety (Sarjoo-52). When compared to better parent, significant earlier flowering plants were observed in thirty one crosses while; eight crosses were identified for late flowering. The magnitude of heterosis observed over better parent ranged from -16.57% (IR58025A×IR 35454-18-1-1-2R) to 7.27% (NMS4A×IR 53480-8-39-3-1-2R) with a mean of -3.04% over the better parent, the magnitude of standard heterosis ranged from -4.22% (IR58025A×IR 58110-114-2-2-2R) to -16.57% (IR58025A×IR 35454-18-1-1-2R) with mean value of -9.67%. In general, all the sixty crosses exhibited early flowering over standard variety (Sarjoo-52), while thirty one crosses exhibited significantly early flowering and eight crosses were late flowering as compared over the better parent. The five superior crosses having heterobeltiosis for early flowering were IR58025A×IR 35454-18-1-1-2R, NMS4A×IET 9352, NMS4A×IR 35454-18-1-1-2 R, NMS4A×IR 42686-2-118-6-2R and IR58025A×IR 32419-28-3-1-3R. In respect of standard heterosis the most promising cross combinations for early flowering were IR58025A×IR32419-28-3-1-3R, NMS4A×IR 42686-2-118-6-2R, PMS 10 A×IR 633-76-1 R, PMS 10 A×IR 54853-43-1-3R and PMS10A×NDR358. Heterosis in both negative and positive directions for days to flowering have also been reported by Peng and Virmani (1991), Murthy and Kulkarni (1996). Most data have indicated negative heterosis in days to flowering in hybrids (Chang *et al*., 1971, 1973; Dhulappanavar and Mensikai, 1967; Fujimaki and Yoshida, 1984; Mallick *et al*., 1978; Namboodri, 1963; Purohit, 1972; Xu and Wang, 1980) found that days to maturity in hybrids depend on the male plant. Most hybrids have long growth duration (Deng, 1980; Lin and Yuan, 1980; Tian *et al*., 1980; Wu *et al*., 1980).

Plant height: Semi-dwarf plant height (80-100 cm) is desirable for recording high yield in rice variety as vigour in plant height may lead to unfavourable grain/straw

Table 2: Estimation of heterosis over better parent (BP) and standerd variety (SV) for yield and yeild components in rice

Crosses	Days to 50% flowering		Plant height (cm)		Pollen fertility (%)		Effective tillers per plant		Panicle length (cm)		No. of spikelets per panicle	
	BP	SV	BP	SV	BP	SV	BP	SV	BP	SV	BP	SV
IR58025A×IR 32419-28-3-1-3R	-11.08**	-15.36**	-9.94**	-7.62**	-11.58**	0.00	-18.75**	8.33	32.68**	17.00**	-0.70	6.60**
IR58025A×IET 201108	-4.61**	-12.65**	-15.44**	-13.26**	-5.30*	-79.00	-4.17	27.78**	17.76**	-1.59	-6.33**	0.57
IR58025A×IR 52256-9-2-2-1R	-4.64**	-7.23**	-3.91*	-4.19**	-8.15**	-1.59	-25.00**	0.00	-1.55	-17.72**	1.41	8.87**
IR58025A×IET 9352	-6.87**	-6.02**	-4.87**	-2.42	-13.26**	-3.97	-20.83**	5.56	12.07**	12.39**	1.23	8.68**
IR58025A×IR 42686-2-118-6-2R	-9.26**	-11.45**	-5.14**	-8.42**	0.00	2.78	-16.67**	11.11**	-21.95**	-7.78	-1.58	5.66**
IR58025A×IR 633-76-1R	-8.06**	-7.23**	-11.12**	-12.64**	-1.87	4.37	-26.00**	2.78	18.97**	-0.58	-9.14**	-2.45*
IR58025A×IR 47310-94-4-3-1R	1.97	-6.63**	-3.27*	-4.61**	-9.16**	-1.59	-20.75**	16.67*	-23.79**	-20.61**	-3.51**	3.58**
IR58025A×IR 60966-29-4-2-2-2R	-9.91**	-12.35**	-1.40	-3.96*	-1.58	-1.19	-10.42	19.44*	23.86**	5.48	-4.85**	3.58**
IR58025A×IR 62030-81-1-3-2R	-0.97	-8.13**	-8.66**	-11.52**	-5.38*	-2.38	0.00	33.33**	24.71**	22.19**	-8.61**	-1.89*
IR58025A×IR 46R	-1.36	-12.65**	-6.36**	-7.33**	-3.08	0.00	-8.33	22.22**	-19.65**	-8.65	-3.34**	3.77**
IR58025A×IR 58110-114-2-2-2R	3.58**	-4.22**	-15.99**	-13.83**	0.40	0.40	-30.77**	0.00	-22.35**	-22.91**	-20.88**	-11.32**
IR58025A×IR 48749-53-2-2-2R	1.29	-5.72**	-2.33	0.18	-1.54	1.59	20.83**	5.56	20.69**	0.86	-8.96**	-2.26*
IR58025A×IR 19058-170-1R	0.00	-11.75**	-3.74*	-13.38**	-8.12**	-1.19	8.33	44.44**	2.41	16.14**	-5.33	4.15**
IR58025A×IET 201102	-3.18*	-8.43**	-2.76	-7.14**	1.55	3.97	15.69**	63.89**	31.23**	19.88**	1.58	9.06**
IR58025A×IR 35454-18-1-1-2R	16.57**	-16.57**	-12.56**	-12.95**	5.28*	2.78	-20.83**	5.56	-30.26**	-27.95**	-8.79**	-2.08*
IR58025A×IR 54853-43-1-3R	-0.65	-7.53**	-4.81**	-8.71**	0.38	3.97	-17.31**	19.44**	20.69**	0.86	-4.22**	2.83**
IR58025A×IR 53480-8-39-3-1-2R	0.69	-12.35**	12.50**	-16.63**	2.39	1.98	-12.50**	16.67**	-13.36**	-20.61**	7.30**	0.57
IR58025A×NDR 6054	-1.34	-11.14**	-16.99**	-14.86**	-9.12**	-1.19	-10.42	19.44**	2.07	6.77	2.28**	9.81**
IR58025A×NDR 358	6.16**	-6.63**	3.28	-6.00**	-4.62	-1.59	-2.08	30.56**	15.86*	-3.17	-3.16**	3.96**
IR58025A×NDR 3008	-5.18**	-11.75**	-16.53**	-14.39**	-8.60**	1.19	-12.50*	16.67*	-24.90**	-20.89**	-21.79**	-16.04**
NMS4A×IR 32419-28-3-1-3R	-0.63	-5.42**	-11.85**	-13.41**	-8.07**	3.97	-24.00**	5.56	-13.08*	-15.71**	-15.41**	-15.09**
NMS4A×IET 201108	-1.97	-10.24**	-2.17	-3.90	-0.76	3.97	0.00	38.89**	7.28	4.03	-2.38*	0.57
NMS4A×IR 52256-9-2-2-1R	-6.81**	-9.34**	-5.92**	-7.59**	-5.93*	0.79	16.00*	61.11**	24.52**	20.75**	-0.72	3.96**
NMS4A×IET 9352	-13.91**	-12.35**	0.84	-0.95	-4.30	5.95**	-6.00	30.56**	2.87	3.17	-1.50	-1.13
NMS4A×IR 42686-2-118-6-2R	-12.96**	-15.05**	-16.74**	-19.62**	-0.39	2.38	-26.00**	2.78	-40.12**	-29.25**	-8.27**	-7.92**
NMS4A×IR 633-76-1R	-6.27**	-5.42**	-11.46**	-13.03**	-6.34**	-0.40	-14.00**	19.44*	1.63	-1.44	-4.73**	-1.13
NMS4A×IR 47310-94-4-3-1R	-2.63**	-10.84**	-6.74**	-8.39**	-4.76*	3.17	-24.53**	11.11	-1.24	2.88	8.65**	9.06**
NMS4A×IR 60966-29-4-2-2-2R	-3.41**	-6.02**	-12.22**	-14.51**	-2.37	-1.98	-6.00	30.56**	24.67**	20.89*	-0.52	8.30**
NMS4A×IR 62030-81-1-3-2R	-6.17**	-12.95**	-13.69**	-16.40**	-2.69	0.40	4.00	44.44**	20.44**	18.01*	-3.64**	-0.19
NMS4A×IR 46R	5.10**	-6.93**	-6.08**	-7.74**	0.38	3.57	2.00	41.67**	-32.07**	-22.77**	-18.62**	-13.40**
NMS4A×IR58110-1-114-2-2-2R	1.63	-6.02**	-13.53**	-15.07**	-3.17	-3.17	-11.54*	27.78**	12.77**	11.96*	-8.08*	3.02**
NMS4A×IR 48749-53-2-2-2R	-5.83**	-12.35**	-4.15*	-5.85**	-4.62	-1.59	-34.00**	-8.33	1.49	-1.59	-5.83**	-5.47**
NMS4A×IR 19058-170-1R	-1.02	12.65**	-3.38*	-13.06**	-8.86**	-1.98	-20.00**	11.11	6.35	20.61**	-9.09**	0.00
NMS4A×IET 201102	-2.55*	-7.83**	4.69**	-0.32	-15.12**	-13.10**	-11.76**	25.00**	-19.47**	-21.90**	-12.41**	12.08**
NMS4A×IR 35454-18-1-1-2R	-13.25**	-13.25**	-3.82*	-5.52**	2.44	0.00	20.00**	66.67**	19.25**	23.20**	6.27**	8.68**
NMS4A×IR 54853-43-1-3R	-4.85**	-11.45**	-9.98**	-13.68**	-2.68	0.79	-7.69	33.33**	-25.85**	-28.10**	-21.35**	-18.68**
NMS4A×IR 53480-8-39-3-1-2R	7.27**	-6.63**	-4.43**	-8.95**	1.59	1.19	26.00**	75.00**	22.14**	18.44**	-6.09**	1.89*
NMS4A×NDR 6054	-2.68*	-12.35**	-11.34**	-12.91**	-7.66**	0.40	-18.00**	13.89	-5.51	-1.15	-8.46**	-8.11**
NMS4A×NDR 358	5.48**	-7.23**	3.93*	-5.41**	0.00	3.17	4.00	44.44**	-28.68**	-30.84**	-20.29**	-17.74**
NMS4A×NDR 3008	-6.80**	-13.25**	1.38	-0.41	-10.39**	-0.79	-2.00	36.11**	-39.26**	-36.02**	-7.98**	-6.42**
PMS10A×IR 32419-28-3-1-3R	7.91**	-12.35**	-0.09	-5.26**	-12.63**	-1.19	-23.26**	-8.33	0.33	-11.53**	-7.61**	3.02**
PMS10A×IET 201108	0.99	-7.53**	3.58*	-1.77	-6.44**	-1.98	-4.17	27.78**	48.30**	13.26**	-2.71**	8.49**
PMS10A×IR 52256-9-2-2-1R	-3.47**	-7.83**	-8.75**	-13.47**	-8.15**	-1.59	32.56**	58.33**	5.74	20.22**	-12.01**	1.89*
PMS10A×IET 9352	-7.26**	-11.45**	-3.21*	-8.21**	-8.24**	1.59	-16.28*	0.00	-7.33	-7.06	-0.34	11.13**
PMS10A×IR 42686-2-118-6-2R	-2.21	-6.63**	4.17*	-1.21	-5.02*	-2.38	4.65	25.00**	-2.80	14.84*	-16.41**	-6.79**
PMS10A×IR 633-76-1R	-9.15**	-13.25**	-8.94**	-13.65**	-6.72*	-0.79	-16.00*	16.67*	-6.02	-25.79**	-21.66**	-12.64**

Table 2: Continue

	Days to 50% flowering		Plant height (cm)		Pollen fertility (%)		Effective tillers per plant		Panicle length (cm)		No. of spikelets per panicle	
Crosses	BP	SV	BP	SV	BP	SV	BP	SV	BP	SV	BP	SV
PMS10A×IR 47310-94-4-3-1R	0.33	-8.13**	-3.55*	-8.54**	-8.06**	-0.40	-20.75**	16.67*	-7.05	-3.17	-7.61**	3.02**
PMS10A×IR 60966-29-4-2-2-2R	-2.21	-6.63**	-5.58**	-10.46**	9.49**	9.92**	37.21**	63.89**	40.78**	19.88**	-4.57**	6.42**
PMS10A×IR 62030-81-1-3-2R	-4.87**	-11.75**	-1.43	-6.53**	-1.92	1.19	-16.28*	0.00	-38.24**	-39.48**	-18.27**	-8.87**
PMS10A×IR 46R	4.08**	-7.83**	8.29**	-13.03**	-5.77*	-2.78	-2.33	16.67*	-6.84	5.91	-7.78**	2.83**
PMS10A×IR 58110-114-2-2-2R	-1.30	-8.73**	-9.94**	-14.59**	1.98	1.98	-28.85**	2.78	-18.29**	-18.88**	-8.90**	2.45*
PMS10A×IR 48749-53-2-2-2R	-5.83**	-12.35**	-3.86*	-8.83**	-3.46	-0.40	20.93**	44.41**	7.96	-13.98*	-19.63**	-10.38**
PMS10A×IR 19058-170-1R	5.80**	-6.63**	-1.74	-11.58**	-6.64**	0.40	-18.60*	-2.78	-14.23**	-2.74	-15.40**	-5.66**
PMS10A×IET 201102	1.27	-4.42**	-10.09**	-14.74**	-5.04*	-2.78	0.00	41.67**	20.82**	10.37	-9.48**	0.94
PMS10A×IR 35454-18-1-1-2R	-6.94**	-11.14**	1.31	-3.93**	4.47	1.98	39.53**	66.67**	9.62	13.26*	-7.61**	3.02**
PMS10A×IR 54853-43-1-3R	-6.15**	-12.65**	-8.88**	-13.59**	-5.75*	-2.38	-5.77	36.11**	29.52**	4.52	-10.83**	0.57
PMS10A×IR 53480-8-39-3-1-2R	6.23**	-7.53**	-1.46	-6.56**	5.18*	4.76	-14.58**	13.89	-35.22**	-40.63**	-40.44**	-33.58**
PMS10A×NDR 6054	1.00	-10.84**	-7.29**	-12.08**	-4.38	3.97	-9.30	8.33	-23.83**	-20.32**	-38.58**	-31.51**
PMS10A×NDR 358	-0.68	-12.65**	-2.50	-11.26**	-4.62	-1.59	16.28**	38.89**	10.33	-12.25**	-8.46**	2.08*
PMS10A×NDR 3008	0.32	-6.63**	-0.50	-5.64**	-6.09**	3.97	0.00	19.44**	5.20	10.81	-7.11**	3.58**
Mean	-3.04	-9.67	-5.98	-9.26	-4.05	0.43	-6.88	24.44	0.37	-3.65	-8.63	-1.69
No. of hybrids with significant +Ve heterosis	8	0	5	0	3	4	9	41	20	16	3	29
No. of hybrids with significant -Ve heterosis	31	60	43	53	29	1	29	0	19	22	48	22

	No. of fertile spikelets		Spikelet fertility (%)		100-grain weight (g)		Grain yield per plant (g)		Biological yield (g)		Harvest index (%)	
Crosses	BP	SV	BP	SV	BP	SV	BP	SV	BP	SV	BP	SV
IR58025A×IR 32419-28-3-1-3R	25.58**	12.24**	14.68**	5.19**	-3.68	-9.03	48.77**	64.35**	8.33**	27.48**	36.89**	28.85**
IR58025A×IET 201108	28.65**	5.77**	31.78**	5.09**	20.25**	-5.97	37.72**	37.16**	-11.76**	4.25	56.06**	31.50**
IR58025A×IR 52256-9-2-2-1R	11.52**	11.78**	7.29**	2.60	-24.51**	-30.28**	38.83**	58.10**	9.02**	28.29**	-6.63	23.27**
IR58025A×IET 9352	29.48**	8.55**	3.83*	-0.22	51.09**	5.97	23.71**	17.82**	-22.54**	-8.85**	33.19**	29.13**
IR58025A×IR 42686-2-118-6-2R	27.42**	12.70**	10.95**	6.58**	-15.66**	-31.94**	12.68**	28.16**	12.50**	32.38**	-9.21*	-3.19
IR58025A×IR 633-76-1R	31.02**	0.46	39.38**	2.88	-26.94**	-26.94**	35.44**	28.44**	-13.94**	1.27	5.27	26.59**
IR58025A×IR 47310-94-4-3-1R	30.51**	6.70**	10.77**	2.89	22.13**	3.47	5.11	14.69**	-22.89**	-9.26**	11.11**	26.39**
IR58025A×IR 60966-29-4-2-2-2R	12.69**	4.62**	18.46**	0.91	-3.82	-30.14**	47.55**	47.35**	5.86*	10.78**	6.48	32.91**
IR58025A×IR 62030-81-1-3-2R	25.00**	-3.00*	35.23**	1.21	-24.57**	-32.22**	34.45**	33.71**	7.80**	26.86**	18.91**	5.39
IR58025A×IR 46R	8.82**	8.31**	14.38**	7.26**	-0.76	-9.72	57.82**	49.02**	-2.50	14.73**	37.07**	29.84**
IR58025A×IR 58110-114-2-2-2R	-19.02**	-4.62**	2.38	7.48**	-10.38**	-24.44**	-5.02	8.98	-9.00**	15.90**	4.04	-6.16
IR58025A×IR 48749-53-2-2-2R	-2.95*	-1.15	-0.54	1.05	34.79**	-14.44	113.04**	54.29**	5.65*	24.32**	54.08**	24.07**
IR58025A×IR 19058-170-1R	6.05**	9.24**	12.00**	4.79**	-3.40	6.67	74.93**	71.43**	11.29**	30.97**	-2.25	30.84**
IR58025A×IET 201102	16.55**	13.86**	5.27**	4.33**	65.31**	12.50	34.76**	50.75**	-3.58	13.47**	17.26**	32.67**
IR58025A×IR 35454-18-1-1-2R	3.50*	2.31	8.10**	4.38**	7.01	8.19	-0.25	7.07	6.03*	24.78**	-30.18**	-14.22**
IR58025A×IR 54853-43-1-3R	0.43	6.70**	0.99	3.68*	-4.50	-26.25**	78.73**	41.77**	-2.16	15.14**	47.70**	22.90**
IR58025A×IR 53480-8-39-3-1-2R	-4.97**	6.00**	2.53	5.32**	-26.81**	-24.17**	0.12	11.84*	3.88	22.24**	-31.56**	-8.62
IR58025A×NDR 6054	26.84**	11.32**	6.81**	1.29	-7.65	5.56	58.64**	52.38**	8.84**	28.08**	20.46**	18.98**
IR58025A×NDR 358	11.98**	12.24**	11.20**	7.88**	36.49**	-8.06	42.15**	13.33*	-0.73	16.81**	5.37	-3.09
IR58025A×NDR 3008	-20.66**	-11.32**	-3.92**	5.52**	-35.71**	-30.97**	2.32	8.72	-14.61**	2.26	19.74**	6.16
NMS4A×IR 32419-28-3-1-3R	10.59**	-1.15	26.80**	16.31**	-29.12**	-33.06**	-5.91	3.95	-2.21	21.08**	-8.91	-14.26**
NMS4A×IET 201108	27.81**	5.08**	30.91**	4.40**	32.74**	3.79	13.66*	13.20*	-18.89**	0.43	33.61**	12.59*
NMS4A×IR 52256-9-2-2-1R	14.75**	15.01**	15.58**	10.53**	-29.01**	-28.89**	40.98**	60.54**	1.38	25.54**	-3.07	27.98**
NMS4A×IET 9352	17.08**	-1.85	3.21*	-0.81	62.97**	14.31	67.29**	59.32**	0.45	24.37**	32.12**	28.09**

Table 2: Continue

Crosses	No. of fertile spikelets		Spikelet fertility (%)		100-grain weight (g)		Grain yield per plant (g)		Biological yield (g)		Harvest index (%)	
	BP	SV	BP	SV	BP	SV	BP	SV	BP	SV	BP	SV
NMS4A×IR 42686-2-118-6-2R	11.49**	-1.39	11.40**	7.02**	-4.13	-22.64**	-0.36	13.33*	-1.84	21.53**	-12.54**	-6.75
NMS4A×IR 633-76-1R	39.46**	6.93**	46.40**	8.07**	-31.53**	-31.53**	80.92**	71.56**	9.18**	35.18**	5.63	27.03**
NMS4A×IR 47310-94-4-3-1R	46.61**	19.86**	17.31**	8.97**	36.56**	15.69*	26.68**	38.23**	3.03	27.57**	-4.70	8.42
NMS4A×IR 60966-29-4-2-2-2R	17.16**	8.78**	17.80**	0.35	6.50	-22.64**	48.64**	48.44**	2.29	26.65**	-6.13	17.16**
NMS4A×IR 62030-81-1-3-2R	29.46**	0.46	34.36**	0.56	19.78**	7.64	44.46**	43.67**	-5.86**	16.56**	38.96**	23.15**
NMS4A×IR 46R	-8.12**	-8.55**	12.51**	5.51**	-35.42**	41.25**	21.90**	15.10**	-8.40**	13.42**	7.32	1.66
NMS4A×IR58110-1-114-2-2-2R	-9.80**	6.24**	-1.86	3.03*	10.38	6.94	33.20**	52.83**	-10.99**	13.37**	49.35**	34.71**
NMS4A×IR 48749-53-2-2-2R	0.00	1.85	5.95**	7.64**	20.57	-23.47**	27.75**	-7.48	-35.31**	-19.91**	43.26**	15.36**
NMS4A×IR 19058-170-1R	-2.91*	0.00	6.78**	-0.09	2.26	12.92	16.90**	14.56**	-9.83**	11.64**	-23.28**	2.70
NMS4A×IET 201102	-5.20**	-7.39**	6.17**	5.23**	-1.43	-32.92**	-7.41	3.58	-11.02**	10.17**	-16.86**	5.94
NMS4A×IR 35454-18-1-1-2R	21.03**	19.63**	13.88**	9.97**	8.65	9.86	53.49**	64.76**	-3.73	19.20**	12.41**	38.13**
NMS4A×IR 54853-43-1-3R	-20.43**	-15.47**	1.15	3.84*	-26.80**	-43.47**	18.18**	-6.26	-10.24**	11.14**	1.44	-15.59**
NMS4A×IR 53480-8-39-3-1-2R	-4.97**	6.00**	1.20	3.95*	-2.14	1.39	-4.38	6.80	-20.89**	2.05	-18.14**	9.29
NMS4A×NDR 6054	5.26**	-7.62**	5.91**	0.44	0.61	15.00	41.50**	35.92**	-4.22	18.59**	15.86**	14.43**
NMS4A×NDR 358	-17.05**	-16.86**	4.08*	0.97	-9.28	-38.89**	31.23**	4.63	-3.32	19.71**	-5.08	-12.71**
NMS4A×NDR 3008	-11.57**	-1.15	-3.89**	5.55**	3.88	11.53	8.71	15.51**	-7.54**	14.48**	13.71**	0.80
PMS10A×IR 32419-28-3-1-3R	14.73**	2.54	8.41**	-0.55	13.97	7.64	0.37	10.88**	-0.44	16.66**	1.03	-4.91
PMS10A×IET 201108	44.10**	18.48**	36.32**	8.71**	42.63**	11.53	46.31**	45.71**	4.91*	23.93**	39.41**	17.48**
PMS10A×IR 52256-9-2-2-1R	-2.07	1.85	4.53**	-0.04	-21.95**	-27.92**	-0.96	12.79**	-0.18	14.89**	-25.49**	-1.64
PMS10A×IET 9352	34.16**	12.47**	5.22**	1.13	37.23**	-3.75	42.43**	35.65**	8.46**	24.83**	12.02*	8.60
PMS10A×IR 42686-2-118-6-2R	7.05**	-5.31**	5.67**	1.52	-13.43	-30.14**	-19.86**	-8.84	-17.10**	-4.59	-9.35*	-3.34
PMS10A×IR 633-76-1R	14.16**	-12.47**	35.63**	0.11	-41.25**	-41.25**	19.66**	13.47*	0.66	15.85**	-18.63**	-2.15
PMS10A×IR 47310-94-4-3-1R	28.81**	5.31**	9.95**	2.14	20.16*	1.81	-6.98	1.50	-16.22**	-3.58	-8.26	4.36
PMS10A×IR 60966-29-4-2-2-2R	14.68**	6.47**	17.33**	-0.05	20.84*	-12.22**	35.15**	34.97**	-10.70**	2.78	5.13	31.22**
PMS10A×IR 62030-81-1-3-2R	26.79**	-1.62	44.10**	7.86**	-20.09*	-28.19**	11.63*	11.02*	0.62	15.80**	8.30	-4.02
PMS10A×IR 46R	8.58**	8.08**	11.97**	5.00**	-32.37**	-38.47**	17.60**	10.48	5.24*	21.13**	-3.80	-8.87
PMS10A×IR 58110-114-2-2-2R	-3.53*	-13.63**	5.54**	10.80**	26.85**	6.94	1.03	15.92**	-19.95**	1.95	25.97**	13.63**
PMS10A×IR 48749-53-2-2-2R	-9.98**	-8.31**	0.61	2.22	18.16	-25.00**	32.07**	-4.35	-2.82	11.84	6.27	-14.43**
PMS10A×IR 19058-170-1R	-3.36**	-0.46	12.69**	5.43**	-8.55	0.97	23.98**	21.50**	-14.24**	-1.29	-7.93	23.24**
PMS10A×IET 201102	8.51**	6.00**	6.34**	5.39**	71.63**	16.81*	16.69**	28.30**	4.94*	20.77**	-6.09	6.25
PMS10A×IR 35454-18-1-1-2R	14.02**	12.70**	13.18**	9.29**	18.54*	19.86*	45.88**	56.60**	-7.45**	6.52	19.58**	46.93**
PMS10A×IR 54853-43-1-3R	-5.65**	0.23	-1.91	0.70	57.73**	21.81**	73.53**	37.69**	8.90**	25.34**	32.01**	9.85*
PMS10A×IR 53480-8-39-3-1-2R	-3.11*	8.08**	-2.59	0.06	-37.80**	-35.14**	-36.05**	-28.57**	-30.01**	-19.45**	33.17**	-10.77*
PMS10A×NDR 6054	37.89**	21.02**	6.91**	1.39	39.85**	-31.25**	-4.96	-8.71	-10.84**	2.61	-9.90*	-11.01*
PMS10A×NDR 358	7.14**	7.39**	8.34**	5.10**	36.49**	-8.06	52.39**	21.50**	4.58**	20.37**	9.63	0.82
PMS10A×NDR 3008 5.17**	6.00**	-6.89**	2.26	9.06	17.08*	36.75**	45.31**	-6.18**	12.35**	45.82**	29.27**	
Mean	10.61	3.99	11.81	4.17	8.15	-11.21	28.05	26.74	-4.53	13.99	8.85	11.18
No. of hybrids with significant +Ve heterosis	40	34	47	35	19	6	43	46	16	45	26	30
No. of hybrids with significant -Ve heterosis	17	12	3	0	16	28	2	1	25	4	12	7

*Significant at 5% 11 and **1% probablity level of significance

Table 3: Best crosses with their sca effects in relation to *per se* performance involved for different characters in rice

Characters	Best hybrids on the basis of *per se* performance	Best specific combiners	Best common crosses
Days to 50% flowering	IR58025A×IR 35454-18-1-1-2R	PMS10A×IR 633-76-1R	
	NMS4A×IR 35454-18-1-1-2R	IR58025A×IR32419-28-3-1-3R	
	NMS4A×IET 9352	PMS10A×NDR 358	IR58025A×IR 32419-28-3-1-3R
	NMS4A×IR 42686-2-118-6-2R	IR58025A×IR 60966-29-4-2-2R	
	IR58025A×IR 32419-28-3-1-3R	IR58025A×IR 42686-2-118-6-2R	
Plant height	IR58025A×NDR 6054	NMS4A×IR 42686-2-118-6-2R	
	IR58025A×NDR-3008	IR58025A×NDR 3008	
	NMS4A×IR 42686-2-118-6-2R	PMS10A×IET 201102	IR58025A×IET-201108
	IR58025A×IR 58110-114-2-2-2R	IR58025A×IET 201108	NMS4A×IR 42686-2-118-6-2R
	IR58025A×IET 201108	IR58025A×IR 32719-28-3-1-3R	IR58025A×NDR 3008
Pollen fertility percent	PMS10A×IR 60966-29-4-2-2-2R	IR58025A×IET 201102	IR58025A×NDR 3008
	IR58025A×IR 35454-18-1-1-2R	PMS10A×IR 60966-29-4-2-2-2R	PMS10A×IR 60966-29-4-2-2-2R
	PMS10A×IR 32419-28-3-1-3R	NMS4A×IR 53915-43-3-3-3R	
	PMS10A×IR 35454-18-1-1-2R	NMS4A×IET 201108	
	IR58025A×IR 32419-28-3-1-3R	NMS4A×IR 46R	
Panicle bearing tillers (Effective tillers) per plant	PMS10A×IR 35454-18--1-1-2R	NMS4A×IR 32419-28-3-1-3R	
	PMS10A×IR 60966-29-4-2-2-2R	IR58025A×IR 19058-107-1R	PMS10A×IR 60966-29-4-2-2-2R
	PMS10A×IR 52256-9-2-2-1R	PMS10 A×IR 48749-53-2-2-2R	NMS4A×IR 32419-28-3-1-3R
	NMS4A×IR 32419-28-3-1-3R	IR58025A×IET 201102	
	NMS4A×IR 35454-18-1-1-2R	PMS10A×IR 60966-29-4-2-2-2R	
Panicle length	PMS10A×IET 201108	NMS4A×IR 32419-28-3-1-3R	
	PMS10A×IR 60966-29-4-2-2-2R	PMS10A×NDR 3008	
	IR58025A×IR 32419-28-3-1-3R	NMS4A×IR 52256-9-2-2-1R	Nil
	IR58025A×IET 201102	PMS10A×IR 42686-2-118-6-2R	
	PMS10A×IR 54853-43-3-3-3R	IR58025A×IR 62030-81-1-3-2R	
No. of spikelets per panicle	NMS4A×IR 47310-94-4-3-1R	IR58025A×NDR 6054	
	NMS4A×IR 35454-18-1-1-2R	NMS4A×IR 32419-28-3-1-3R	
No. of fertile spikelets	NMS4A×IR 633-76-1R	PMS10A×NDR 6054	PMS10A×NDR 6054
	PMS10A×IET 201108	NMS4A×IR 47310-94-4-3-1R	NMS4A×IR 47310-94-4-3-1R
	NMS4A×IR 633-76-1R	NMS4A×IR 633-76-1R	NMS4A×IR 633-76-1R
	PMS10 A×NDR 6054	NMS4A×IR 35454-18-1-1-2R	
	IR58025A×IR 633-76-1R	IR58025A×NDR 358	
Spikelets fertility percent	NMS4A×IR 633-76-1R	NMS4A×IR 32419-28-3-1-3R	NMS4A×IR-633-76-1R
	PMS10A×IR 62030-81-1-3-2R	PMS10A×IR 62030-81-1-3-2R	PMS10A×IR-62030-81-1-3-2R
	IR58025A×IR 633-76-1R	NMS4A×IR 52256-9-2-2-1R	
	PMS10A×IET 201108	PMS10A×IR 58110-114-2-2-2R	
	PMS10A×IR 633-76-1R	NMS4A×IR 633-76-1R	
100 Grain weight	PMS10A×IET 201102	PMS10A×IR 54853-43-1-3R	
	IR58025A×IET 201102	NMS4A×IR 62030-81-1-3-2R	PMS10A×IR 54853-43-1-3R
	NMS4A×IR 53915-43-3-3-3R	IR58025A×IR 46R	
	PMS10A×IR 54853-43-3-3-3R	NMS4A×IR 32419-28-3-1-3R	
	IR58025A×IET 9352	NMS4A×NDR 6054	
Grain yield per plant	IR58025A×IR 48749-53-2-2-2R	NMS4A×IR 633-76-1R	IR58025A×IR 48749-53-2-2-2R
	NMS4A×IR 633-76-1R	IR58025A×IR 48749-53-2-2-2R	NMS4A×IR 633-76-1R
	IR58025A×IR 54853-43-1-3R	PMS10A×NDR 3008	IR58025A×IR 19058-170-1R
	IR58025A×IR 19058-170-1R	IR58025A×IR 48749-53-2-2-2R	
	PMS10A×IR 54853-43-3-3-3R	IR58025A×IR 19058-170-1R	
Bilogical yield	IR58025A×IR 42686-2-118-6-2R	NMS4A×IR 47310-94-4-3-1R	NMS 4A×IR 633-76-1R
	IR58025A×IR 19058-170-1R	IR58025A×IR 32419-28-3-1-3R	
	NMS4A×IR 633-76-1R	PMS10A×IET 201108	
	IR58025A×IR 52256-9-2-2-1R	IR58025A×IR 48749-53-2-2-2R	
	IR58025A×NDR 6054	NMS4A×IR 633-76-1R	
Harvest index	IR58025A×IET 201108	PMS10A×IR 35454-18-1-1-2R	NMS4A×IR 58110-114-2-2-2R
	IR58025A×IR 48749-53-2-2-2R	PMS10A×NDR 3008	
	NMS4A×IR 58110-114-2-2-2R	NMS4A×IR 58110-114-2-2-2R	
	IR58025A×IR 54853-43-1-3R	IR58025A×IR 32419-28-3-1-3R	
	PMS10A×NDR 358	IR58025A×IR 46R	

ratios and below optimum yield due to lodging. The minimum amount of heterosis -16.99% (IR 58025A×NDR6054)and-19.62%(NMS4A×IR42686-2-118-6-2R) was recorded over better parent and standard variety, respectively. However, the maximum significant heterosis observed over the better parent was 8.29% (PMS10A×IR46R), while in case of standard heterosis, it was 0.18% (IR58025A×IR 48749-53-2-2-2R) and mean heterosis over better parent and standard variety was 5.98 and -9.26% respectively. Five crosses namely NMS4A×IET 201102, NMS4A×NDR 358, PMS10A×IET201108, PMS10A×IR 42686-2-118-6-2R and

PMS10A×IR46R exhibited significant positive heterobeltiosis, whereas forty three and fifty three crosses expressed dwarf stature in comparison to both better parent and standard variety, it was obvious from the data (Table 2) that the hybrid combinations have a tendency of dwarfness of trait in most of the cases. In respect of the most promising cross combinations for dwarfness were IR58025A×NDR 6054, NMS4A×IR42686-2-118-6-2R, IR58025A×NDR3008,IR58025A×IR58110-114-2-2-2Rand IR 58025A×IET201108. None of the desirable combinations were common for both the heterosis, suggesting that heterosis for plant height is cross specific. Present observations are in close agreement with earlier report of several workers (Pillai, 1961; Sivasubranian and Menon, 1973.; Khalique *et al*., 1977; Mallick *et al*., 1978; Singh *et al*., 1996; Arnirthadeverathinam, 1983; Tseng and Huang, 1987; Sharma and Mani, 1989; Peng and Virmani, 1991; Lokaprakash *et al*., 1992; Nuruzzaman *et al*., 2002; Alam *et al.,* 2004).

Pollen fertility percent: Pollen fertility is one of the constraints in hybrid rice breeding programme, which affects the yield considerably. Among 60 crosses studied for pollen fertility percent, only three and four hybrids showed significant positive heterosis over pollen parent and standard variety respectively. The overall range of heterobeltiosis and standard heterosis varied from -15.12 to 9.49%, respectively. However, pollen fertility in hybrids should be required as in pollen parent and or standard variety this indicates that the pollen parent in hybrid expressed full restoring capacity over a particular CMS line. Therefore, hybrids having non-significant differences over both the parents (BP and SV) either in positive or negative direction would be beneficial for this trait. The seven crosses and twenty eight cross combinations had positive but non-significant differences for both heterobeltiosis and standard heterosis; of these, PMS10A×IR35454-18-1-1-2R,IR58025A×IR53480-8-39-3-1-2R, PMS10A×IR58110-114-2-2-2R, NMS4A×IR 46R and NMS4A×IR 53480-8-39-3-1-2R were most useful crosses for this trait.

Panicle bearing tillers (Effective tillers) per plant: More panicle bearing tillers per plant is believed to be closely associated with high grain yield per plant resulting high productivity. Therefore, the cross combinations with more panicle bearing tillers per plant were to be identified. The significant positive heterosis for this trait was exhibited by 9 and 41 hybrids over better parent and standard variety, respectively. The mean heterosis was observed-6.88% over better parent and 24.44% over standard variety. Further the heterobeltiosis varied from -34.00% (NMS4A×IR 48749-53-2-2-2R) to 39.53% (PMS 10×IR 35454-18-1-1-2R) and standard heterosis from -8.33 (NMS4A×IR 48749-53-2-2-2R) to 66.67% (PMS10A×IR 35454-18-1-1-2R). As regards the expression of heterobeltiosis, the most promising crosses were PMS 10A×IR35454-18-1-1-2R, PMS10A×IR60966-29-4-2-2-2R, PMS10A×IR52256-9-2-2-1R, NMS4A×IR53480-8-39-3-1-2R and PMS10A×IR 48749-53-2-2-2R. Considering standard heterosis, the five superior cross combinations wereNMS4A×IR53480-8-39-3-1-2R,NMS4A×IR35454-18-1-1-2R,IR58025A×IET201102,PMS10A×IR60966-29-4-2-2-2R and NMS4A×IR 62030-81-1-3-2R. Results for significantly high number of productive tillers per plant are in comformity with those obtained, by Srivastava and Seshu (1982); Govindraj (1983); Sahai *et al*. (1987); Viraktamath (1987); Manual and Palanisamy, 1989). However these findings are in disagreement with the findings of Virmani *et al*. (1981) who reported hybrids posses significantly lower tillers than mid parent, better parent and check variety.

Panicle length: Generally, larger panicle is associated with high number of grains panicle resulting into higher productivity; therefore, hybrids with positive heterosis for panicle length are desirable. The present study revealed that heterosis for panicle length was relatively low as indicated by mean heterosis of 0.37% over better parent and -3.65% over standard variety. Out of 60 crosses 20 and 16 crosses showed higher panicle length over the better parent and standard variety, respectively, whereas 19 crosses possessed significant negative heterobeltiosis and 22 crosses exhibited negative standard heterosis with shorter panicle. The observed heterobeltiosis values ranged between -39.26 (NMS4A×NDR3008) to 48.30% (PMS10A×IET201108) with a mean of 0.37% and standard heterosis between -40.63 (PMS10A×IR53480-8-39-3-1-2R) to 23.20% (PMS10A×IR 35454-18-1-1-2R) in case of standard heterosis with mean of -3.65 per cent. The five superior cross combinations having heterobeltiosis for panicle length were PMS 10A×IET 201108, PMS10A×IR 47310-94-4-3-1R, IR58025A×IR 32419-28-3-1-3R, IR58025A×IET201102 and PMS10A×IR54853-43-1-3R. As regards standard heterosis the most promising crosses for panicle length were NMS4A×IR35454-18-1-1-2R, IR58025A×IR62030-81-1-3-2R, NMS4A×IR60966-29-4-2-2-2R, NMS4A×IR52256-9-2-2-1R and IR58025A×IET201102. Similar findings were also reported by Rao (1965), Karunakaran (1968); Chang *et al*. (1973); Anandakumar and Sreeranagasamy (1984); Rangaswami and Natarajamoorthy, 1988); Vivekanandan (1991); Lokaprakash *et al*. (1992) and Singh *et al*. (1992) who observed positive as well as negative heterosis for panicle length.

Number of spikelets per panicle: For number of spikelets per panicle, the hybrids with positive heterosis are desirable. The lowest estimates of heterosis (-40.44%) over better parent and (-33.58%) standard variety were recorded in the cross PMS10A×IR 53480-8-39-3-1-2R, while, maximum heterosis over better parent and standard variety was observed in case of cross NMS4A×IR47310-94-4-3-1R (8.65%) and NMS4A×IET201102 (12.08%). Out of 60 crosses studied 3 crosses over better parent and 29 crosses over standard variety exhibited significant higher number of spikelets per panicle. Significantly poor spikelets per panicle over the better parent and standard, variety was observed in 48 and 22 crosses, respectively. The five superior crosses were considering standard heterosis, the superior cross combinations were NMS4A×IET 201102, PMS 10A×IET 9352, IR58025A×NOR 6054, IR58025A×IET 202202 and NMS4A×IR 47310-94-4-3-1R. Results revealed that three hybrids expressed heterosis in desired direction with significant value when tested against better parent and almost 48 hybrids showed heterobeltiosis negative direction over standard variety. Positive heterosis over better parent and standard, variety was reported by Virmani *et al.* (1981, 1982) they concluded that heterosis in yield was primarily due to increased number of spikelets per panicle.

Number of fertile spikelets per panicle: The number of fertile spikelets directly contributes to the seed yield hence positive heterotic effect would be highly desirable. The successful utilization of CMS in development of hybrids is not possible unless the effective restorer lines are identified. In the present study, more number of fertile spikelets is closely associated with high yield per plant resulting in high productivity. Therefore, the main interest is to find out the cross combinations with more number of long and heavy panicle bearing tillers. In the present study, the significant and positive heterosis for this trait was exhibited by 47 and 35 hybrids over better parent and standard variety, respectively. Significant negative heterosis was observed in case of 17 crosses over better parent and in 12 crosses over standard variety with mean heterosis was observed in positive direction for both better parent (10.61%) and standard variety (3.99%). The range of heterosis observed over better parent and standard variety was -20.66% (IR58025A×NDR 3008) to 46.61% (NMS4A×IR 47310-94-4-3-1R) and -16.86% (NMS4A×NDR358) to 21.02% (PMS10A×NDR6054), respectively. The five superior crosses were considering heterobeltiosis were NMS4A×IR 47310-94-4-3-1R, PMS10A×IET201108, NMS4A×IR633-76-1R, PMS 10 A×NDR 6054 and PMS 10 A×IET9352.

Spikelet fertility percent: Spikelet fertility percent is very important in hybrid breeding programme. Since this trait has a direct bearing on the yield, hence manifestation of heterosis in positive direction is desirable for this trait. Out of 60 crosses, 47 expressed positive and significant heterobeltiosis, while 35 crosses expressed this in case of standard heterosis. The range of heterosis over better parent and standard variety varied from -6.89% (PMS10A×NDR3008) to 46.40% (NMS4A×IR633-76-1R) and -0.81% (NMS4A×IET9352) to 16.31% (NMS4A×IR 32419-28-3-1-3R), with mean heterosis of 11.81 and 4.17%, respectively. As regards heterosis over better parent the best crosses were NMS4A×IR 633-76-1R, PMS10A×IR 62030-81-1-3-2R, IR58025A×IR633-76-1R, PMS10A×IR633-76 -1R and IR58025A×IR 62030-81-1-3-2R. Results revealed that 40 hybrids expressed heterosis in desired direction with significant value when tested against better parent and as many as 17 hybrids showed heterosis in negative direction over standard variety. Positive heterosis over better parent and standard variety was reported by Virmani *et al.* (1981) they concluded that heterosis in yield was primarily due to increased fertile spikelets per panicle. These results were in conformity with the results obtained by Srivastava and Seshu (1982), Govindraj (1983), Sahai *et al.* (1987), Viraktamath (1987) and Singh (2000) who reported hybrids posses significantly lower tiller number than mid parent, better parent and check variety.

100 grain weight: The 100 grain weight is one of the important common traits which influence the yield. The extent of heterosis was -41.25% (PMS 10 A×IR 633-76-1R) to 71.63% (PMS10A×IET201102) over better parent with mean of 8.15% and from -43.47% (NMS4A×IR54853-43-1-3R) to 21.81% over standard variety. Significantly higher 100 grain weight was observed in case of 19 crosses when tested against their better parents and 6 crosses against the standard variety. The five best heterosis cross combinations in respect of heterobeltiosis for 100 grain weight were PMS10A×IET201102, IR58025A×IET201102, NMS4A×IET 9352, PMS10A×IR54853-43-1-3R and IR58025A×IET9352. The standard heterosis over the check for five most promising crosses were PMS10A×IR54853-43-1-3R, PMS10A×IR35454-18-1-1-2R, PMS10A×NDR3008, PMS10A×IET201102 and NMS4A×IR47310-94-4-3-1R. Among 60 crosses, 19 and 16 hybrids showed significant heterobeltiosis over better parent in positive and negative direction, respectively, whereas 6 and 28 hybrids exhibited significant heterosis over standard variety in positive and negative direction. Heterosis with respect to 100 grain weight in positive and negative direction have also been reported by

Karunakaran (1968), Carnahan *et al.* (1972), Virmani *et al.* (1981), Srivastava and Seshu (1982), Viraktamath (1987), Manuel and Palanisamy (1989), Sharma and Mani (1989) and Lokaprakash *et al.* (1992).

Grain yield: The grain yield is very complex trait. It is multiplicative end product of several basic components of yield (Grafius, 1959). A number of workers have reported wide range of variation in the expression of heterosis for this character (Rao, 1965; Karunakaran, 1968; Carnahan *et al.*, 1972; Chang *et al.*, 1971; Murayama *et al.*, 1974; Parmar, 1974; Saini and Kumar, 1973; Saini *et al.*, 1974; Maurya and Singh, 1978; Govindraj, 1983; Nijaguna and Mahadevappa, 1983; Panwar *et al.*, 1983; Yoshida and Fujimaki, 1984; Devarathinam, 1984; Cheema and Awan, 1985; Kaushik and Sharma, 1986; Sahai *et al.*, 1987; Virmani *et al.*, 1981; Govindraj, 1983; Tseng and Huang, 1987; Sarwagi and Srivastava, 1988; Sampath *et al.*, 1989; Sharma and Mani, 1989, 1990; Peng and Virmani, 1991; Vivekanandan, 1991; Lokaprakash *et al.*, 1992; Wilfred and Prasad, 1992; Ali and Khan, 1995). From practical point of view, heterosis over standard variety is more relevant. Virmani *et al.* (1981) reported as high standard heterosis as 27 and 34% during wet and dry seasons, respectively. They further suggested that a yield advantage of 20-30% over best available standard variety should be sufficient to encourage farmers to take-up hybrid rice cultivation. In the present investigation about 1/3 combinations exhibited standard heterosis more than 30% among these best crosses in order of merit increased grain yield were IR58025A×IR48749-53-2-2-2R, NMS4A×1R633-76-1R, IR58025A×IR54853-43-1-3R, IR58025A×IR19058-107-IR and PMS10A×IR 54853-43-1-3R. These findings were in close agreement with the earlier findings of (Watanesk, 1993; Patel *et al.*, 1994; Zhang *et al.*, 1994; Rao *et al.*, 1996; Mishra and Pandey, 1998; Nuruzzaman *et al.*, 2002; Li *et al.*, 2002; Faiz *et al.*, 2006; Saleem *et al.*, 2008; Bagheri and Jelodar, 2010; Rahimi *et al.*, 2010). Reddy *et al.* (1984). These findings were in close agreement with the earlier findings of (Watanesk, 1993; Patel *et al.*, 1994; Zhang *et al.*, 1994). In general, F_1 hybrids based on a cytoplasmic genetic male sterile system have shown as much heterosis as F_1 hybrids between conventional cultivars/lines. However, most of the data showed heterosis ranging from about 20% over the midparent to 70% over the better parent and heterobeltiosis ranging about 20 to 40%. China has shown 20-30% higher yield potential for hybrids in large-scale production plots, with wider adaptability than conventionally bred varieties (Hunan Provincial Paddy Rice Heterosis Scientific Research Coordination and Cooperation Group, 1978; Li, 1977; Lin and Yuan, 1980; Wu *et al.*, 1980).

Biological yield: The hybrid, NMS4A×IR 48749-53-2-2-2R (-35.31%) and IR58025A×IR42686-2-118-6-2R (12.50%) had expressed heterosis for this trait over their better parent while, NMS4A×IR48749-53-2-2-2R (-19.91%) and NMS4A×IR633-76-1R, (35.18%) recorded heterosis in case of standard variety (Sarjoo-52). In general, out of 60 hybrids only 16 crosses recorded significantly higher heterobeltiosis while 45 crosses exhibited this in case of the standard heterosis. The top five cross combinations in relation to standard heterosis for biological yield were NMS4A×IR633-76-1R, IR58025A×IR42686-2-118-6-2R, IR58025A×IR19058-170-1R, IR58025A×IR52256-9-2-2-1R and IR58025A×NDR 6054. Significant but negative heterosis was exhibited by 25 and 4 hybrids over better parent and standard variety, respectively. These results are in close agreement with Virmani *et al.* (1993) and Peng and Virmani (1991).

Harvest index: Harvest index which indirectly influences the grain yield through controlling the mechanism of distribution of photosynthates to economic and non-economic organs as such is not a yield component. Therefore, it is an important consideration for genetic improvement. The minimum heterosis for harvest index was -31.56 and -15.59% over better parent and standard variety, respectively in cross IR58025A×IR53480-8-39-3-1-2R and NMS4A×IR54853-43-1-3R, however, the maximum heterosis was 56.06% over better parent in cross IR58025A×IET201108 and 46.93% over standard variety in cross PMS10A×IR 35454-18-1-1-2R. Among 60 cross combinations 26 crosses showed significant positive and 12 showed significant negative heterobeltiosis while 30 crosses showed significant positive heterosis over standard variety. The five crosses having maximum positive heterobeltiosis for harvest index in order of merit were IR58025A×IET 201108, IR58025A×IR 48749-53-2-2-2R, NMS4A×IR58110-114-2-2-2R, IR58025A×IR54853-43-1-3R and PMS10A×NDR 3008. The positive heterosis was also reported by Virmani *et al.* (1982) and Peng and Virmani (1991). On the other hand, 12 and 7 hybrids exhibited significant and negative estimates for both heterobeltiosis and standard heterosis for this trait. The significant and negative heterosis over better parent for harvest index was also reported by Nijaguna and Mahadevappa (1982) and over standard variety by Sarwagi and Srivastava (1988).

Heterosis for grain yield along with heterosis of its components is very important consideration. Forty six cross combinations out yielded the standard check variety, Sarjoo 52, by 10.48 to 71.56%. Out of forty three crosses showing desirable heterobeltiosis for grain yield, 3 and 40 crosses were also found to have significant and positive heterosis for number of spikelets per panicle and number of fertile spikelets, respectively. Similarly, the 29 crosses having standard heterosis for number of spikelets, per panicle also exhibited significant positive standard heterosis for both grain yield and number of fertile spikelets except in four crosses namely PMS10A×IR 32419-28-3-1-3R for number of fertile spikelets per panicle, PMS10A×IR47310-94-4-3-1R,NMS4A×IR53480-8-39-3-1-2R for grain yield and NMS4A×IET 201102 for number of fertile spikelets and grain yield per plant. These observations also corroborate the findings of Rao (1965), Dhulappanavar and Mensikai (1967), Mallick *et al.* (1978), Singh and Singh (1978), Mandal (1982), Sardana and Borthakur (1985), Anandakumar and Sreerangasamy (1984), Viraktamath (1987), Rangaswami and Natarajamoorthy (1988), Sharma and Mani (1989, 1990), Lokaprakash *et al.* (1992) and Bobby and Nadarajan, (1993) for number of fertile spikelets per plant and finding of Pillai (1961), Carnahan *et al.* (1972), Davis and Rutgar (1976), Govindraj (1983), Kumar and Saini (1983), Sutarya (1989), Sharma and Mani (1990), Lokaprakash *et al.* (1992) and Ali and Khan (1995) for fertile grains. Besides above mentioned two traits, the crosses possessing significant positive heterosis for grain yield exhibited significantly superior heterosis for harvest index, biological yield and number of spikelets per panicle in IR58025A×IET 201108, IR58025A×IR 60966-29-4-2-2-2R, IR58025A×NDR 6054 and NMS4A×IR 633-76-1R over better parent and standard variety. Earlier reports on manifestation of considerable heterosis for grain yield associated with biological yield (Virmani *et al.*, 1982; Rangaswami and Natarajamoorthy, 1988; Peng and Virmani, 1991), associated with harvest index (Mohapatra and Mohanty, 1985; Peng and Virmani, 1991; Lokaprakash *et al.*, 1992) and with grain weight and fertile spikelets per panicle (Sharma and Mani, 1990) and Chakraborty *et al.*, (1994) for days to 50% flowering, spikelets panicle and 100 grain weight.

Heterotic combinations for commercial utilization: A hybrid with the potential of being released for commercial cultivation should significantly surpass the yield level of the best locally adapted variety and its CMS component should have to ensure hybrid seed production in bulk quantities. Swaminathan *et al.* (1972) and Virmani *et al.* (1981) have suggested that about 20-30% standard heterosis may be considered sufficient to offset the extra cost of hybrid seeds in self-pollinated crops. In the present investigation, about one third of the total hybrids showed more than 20% standard heterosis for grain yield over standard variety (Sarjoo-52). Considering the heterosis more than 60% as well as significant *sca* effects for major components, the NMS 4A×IR 633-76-1R, IR58025A×IR19058-107-1R and IR58025A×IR32419-28-3-1-3R were most promising combinations and need to be tested on large scale. Besides these, some other crosses viz., NMS4A×IR52256-9-2-2-1R, NMS4A×IET9352 and IR58025A×IET201102, which expressed more than 50% heterosis along with desirable significant *sca* effects for more than six important yield components, may be considered for commercial exploitation.

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